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THE EFFECT OF JAMMING/DECEPTION ON DECISION MAKING

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AFAMRL-TR-84-055

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
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This report documents the results of an experiment to investigate the effects of information jamming and deception on human operator decision making. A man-in-the-loop simulation of an air defense commander's control station was developed to present information to six subjects individually and to collect empirical data on their performance. The experimental scenario required the subjects to observe information from three hypothetical sources about hostile penetrator aircraft in their simulated region of air defense responsibility. The subject maintained continuous control of launch and vectoring of friendly interceptor aircraft with the objective of intercepting the penetrators before they reached a line of eleven possible targets. The three information channels provided the generic types of information available to decision makers in command and control systems. Different levels of data aggregation were simulated to provide information with high timeliness-low precision, medium timeliness-medium precision, or low timeliness-high precision. Jamming and deception were applied singularly and in combinations to the three

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channels. Successful and incorrect intercepts of the penetrator aircraft were used as dependent measures. The results indicate the subjects relied primarily on the most timely channel and consequently their performance was worse when this channel was jammed. Deception on any one channel when the other two channels were available for truth correlation and identification did not significantly affect performance. The lowest number of successful intercepts occurred when one channel contained truth, a second was jammed, and the third contained deception, resulting in an ambiguous situation where the subject could not positively isolate truth. The most disruptive condition resulting in the highest number of incorrect intercepts occurred when the most timely channel was jammed and the most precise channel contained deception.

PREFACE

This report documents the results of an experiment performed by the Air Force Aerospace Medical Research Laboratory (AFAMRL), Human Engineering Division, Technology Development Branch, Manned Threat Quantification (MTQ) Program as part of Program Element 62202F and Project/Task/Work Unit 6893/04/64. This experiment was initiated and partially funded by the AFAMRL Commander as part of the FY83 Laboratory Director Fund Program. Operations and maintenance support was provided by Systems Research Laboratories, Inc., Dayton, Ohio, under Contract F33615-82-C-0511. The principal investigators for this experiment were Capt Mark Felkey, Mr. Donald Monk, and 2d Lt Leonard Stec. The authors wish to acknowledge the many contributions of the following personnel:

Associate Investigators	Mr. Evan Rolek (SRL) Dr. Chris Arbak (SRL)
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Data Analysis	Ms. Sharon Ward (AFAMRL/HEC) Sgt Tracy Johnston (AFAMRL/HEC)
Subject Support	Mr. Kevin Holloran (SRL)
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Sincere appreciation is also expressed to the team of subjects for their dedication during training and data collection.

SUMMARY

The present experiment examined the capability of developing a simulation methodology for assessing the effects of Command, Control, and Communications CounterMeasures (C^3CM) on a human operator. Primarily, the effects on human information processing and decision making when information jamming and deception were applied against a key decision maker in a simulated, air defense, C^3 system were assessed. The man-in-the-loop simulation provides real human operator data and a methodology to assess human operator performance. The subjects' performance exhibited trends from which certain strategies were assessed. Results indicated that operator uncertainty and loss of confidence in ambiguous situations did exist. Specifically, the subjects relied on the most timely information channel. Performance was worse when that channel was jammed. Also, the condition that degraded performance the most was when the most timely channel was jammed and the most precise channel contained deceptive information.

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SECTION 1

INTRODUCTION

Command, Control, and Communications (C^3) systems are basically information systems used by human operators for decision making and control of military forces. Extensive research has been directed towards understanding the human's role as information processor and decision-maker in military C^3 systems. This research has been generally restricted to finding ways to improve the man-machine interface and, consequently, enhance human performance resulting in enhanced C^3 system performance. It is also important, however, to develop techniques to degrade human performance in adversary C^3 systems with the goal of reducing the effectiveness of their weapon systems. This requirement was formalized in 1979 when the Military Services were tasked in DoD Directive 4600.4 to deny hostile commanders the ability to effectively command and control their forces by "attacking" enemy perceptions, decision processes, and control mechanisms. In short, to develop and employ C^3 CounterMeasures (C^3CM).

C^3CM is accomplished by destroying, jamming, or deceiving the enemy commander's information network. The successful conduct of modern warfare relies on the timely transfer of accurate information via a C^3 system. This reliance makes the C^3 system highly vulnerable to information disruption (via jamming or destruction) and deception. Currently there exists a poor understanding of how information processing and decision making is affected when the information environment is intentionally degraded. In particular, the following issues need to be addressed.

(1) If a communication link is degraded, very little is known about the effect on the decision maker in a C^3 system. At what point does he find that information unuseable or switch to an alternate information source? What are the human time delays caused by this action?

(2) Data does not exist on the benefits/tradeoffs of using jamming versus deception in an information system. There is currently no methodology for using these two C^3CM techniques together.

(3) Techniques have not been developed for systematically deceiving decision makers. Which deception techniques work the best and with what timing do you use the techniques? What degree of uncertainty or loss of confidence is caused by using a deception technique?

To gain some insights into these problem areas, a man-in-the-loop simulation of a C^3 operator station was developed and used to collect empirical data on the effects of jamming and deception. Specifically, these research objectives were established: (a) develop a simulation methodology for assessing the effects of Command, Control, and Communications CounterMeasures (C^3CM) on human information processing and decision making; and (b) develop Measures of Effectiveness (MOEs) for information jamming and deception applied against a key decision maker in a simulated air defense, C^3 system.

SECTION 2

EXPERIMENTAL PLAN

EXPERIMENT SCENARIO

To provide some operational realism to the experimental paradigm, we selected the role of commander of fighter-interceptor aircraft assigned to an air defense mission. In a real-world scenario, an Air Defense Commander (ADC) would receive information about penetrator aircraft present in his geographic region of responsibility. This information would primarily come from ground radars dispersed throughout this region. Referring to Figure 1, as penetrators are detected and tracked, the radar sites pass the information to sub-region Filter Centers for examination and comparison with other radar sites. After collating data from several radars, the Filter Centers pass the information to an Air Situation Center (ASC). The ASC collates data from several Filter Centers and passes the information to the ADC, along the communications channel designated Communication Channel 1. This information is highly precise since the penetrator location uncertainty has been reduced by the extensive filtering process, but the additional processing and communication actions reduces the timeliness of the data. Consequently, the ADC can receive critical data directly from the Filter Center or radar site via Communication Channels 2 and 3. This information is more timely, but less precise than the information on Communication Channel 1.

The characteristics of the communication channels are shown in Table I. The precision of the information was controlled by introducing a random level of error, bounded by the percentages shown, to the penetrator location and heading data. Timeliness was controlled by delaying the presentation of the penetrator data by the amounts shown. As a result, the subject was required to resolve the classical commander dilemma of making decisions based on less precise but timely data versus delaying his decision until more precise data is available for consideration. In an air defense scenario, the risk is that the intercept of the penetrating aircraft will be missed because of an incorrect decision or even just the lack of a decision. In a C^3CM application situation, the presence of jamming and deception complicates the ADC's responsibilities. He is now confronted with missing information because of jammed channels and must sort out true data from false data when deception is applied to a channel.

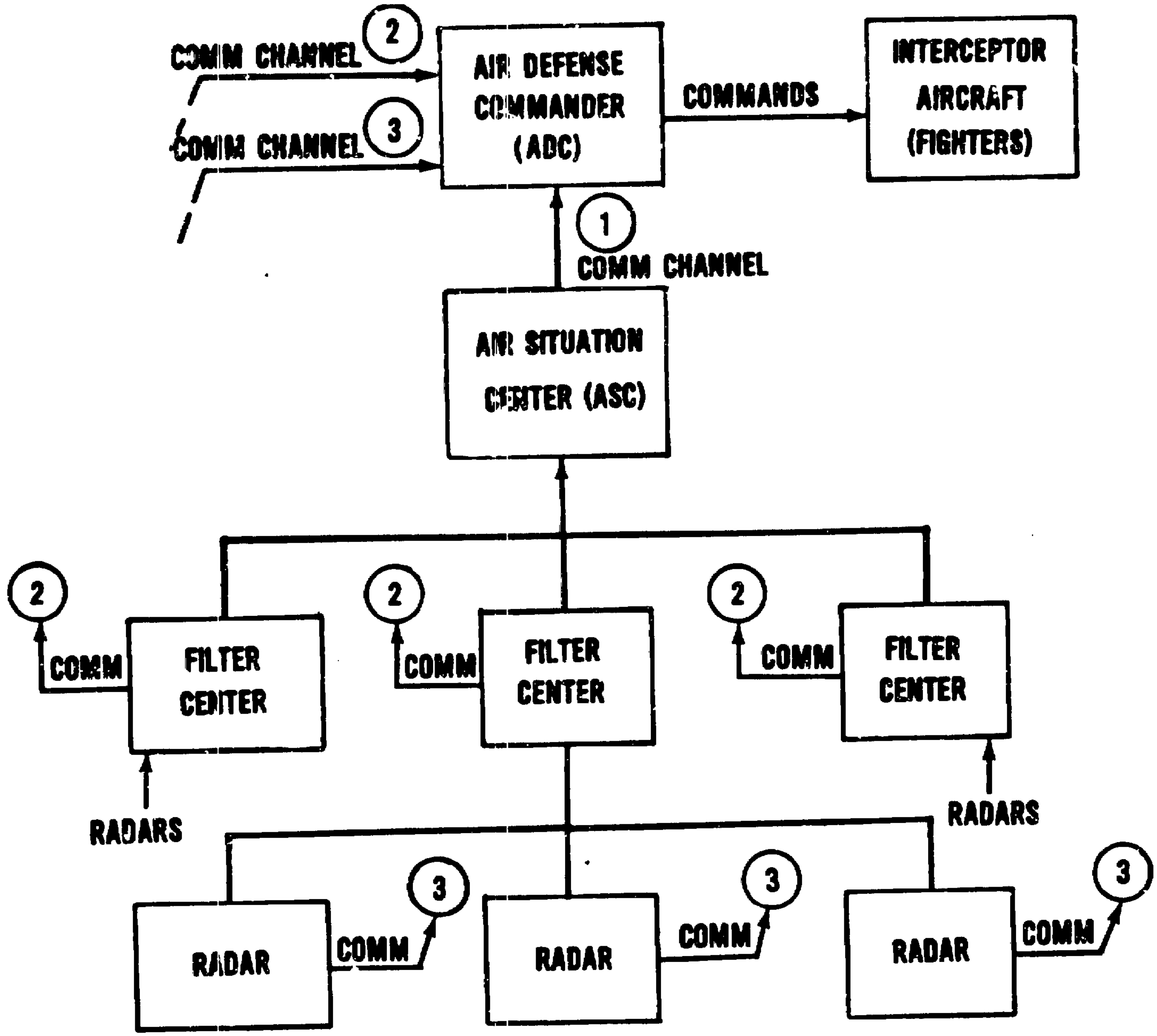


FIGURE 1. INFORMATION FLOW TO THE ADC IN AN AIR DEFENSE SCENARIO.

TABLE I. Channel Characteristics

Channel	Hypothetical Source of Info	Precision (possible error)	Timeliness (delay time)	Update Rate
1	Air Situation Center	High (±5%)	Low (30 sec)	Every 15 sec
2	Filter Centers	Medium (±10%)	Medium (15 sec)	Every 15 sec
3	Radar Sites	Low (±15%)	High (0 sec)	Every 15 sec

For this experiment, the ADC was presented position and heading data for a single group of 10 penetrators moving towards a line of 11 targets. The ADC had 10 interceptors at his disposal to vector to the target area to intercept the penetrators. Reaching the true target before the penetrators was considered a successful intercept. Jamming and deception were applied singularly and in combination on the three channels while the subject (ADC) was directing interceptor aircraft towards the penetrator aircraft. The objective was to delay and/or confuse the subjects' vector control of the interceptors. The subject attempted to sort out true information from deceptive information by correlating data among the communication channels. When jamming was applied, the jammed channel(s) was/were inactive. When deception was applied, the deceived channel presented data indicating the penetrators were moving towards a false target.

SIMULATION DESCRIPTION

The experiment used three computer terminals and a graphics display, all driven by a PDP 11/44 minicomputer. The simulation block diagram shown in Figure 2 indicates the functions of each piece of equipment. The keyboard was used by the subjects to input commands to the simulated interceptor aircraft. As shown in Figure 3, the VT-100, LA-36, and SILENT 700 displayed message-type time, position, and heading data from communication channels 1, 2, and 3, respectively. Simultaneously, the IMLAC PDS-4 automatically plotted the interceptor flight paths and the penetrator positions from all three channels.

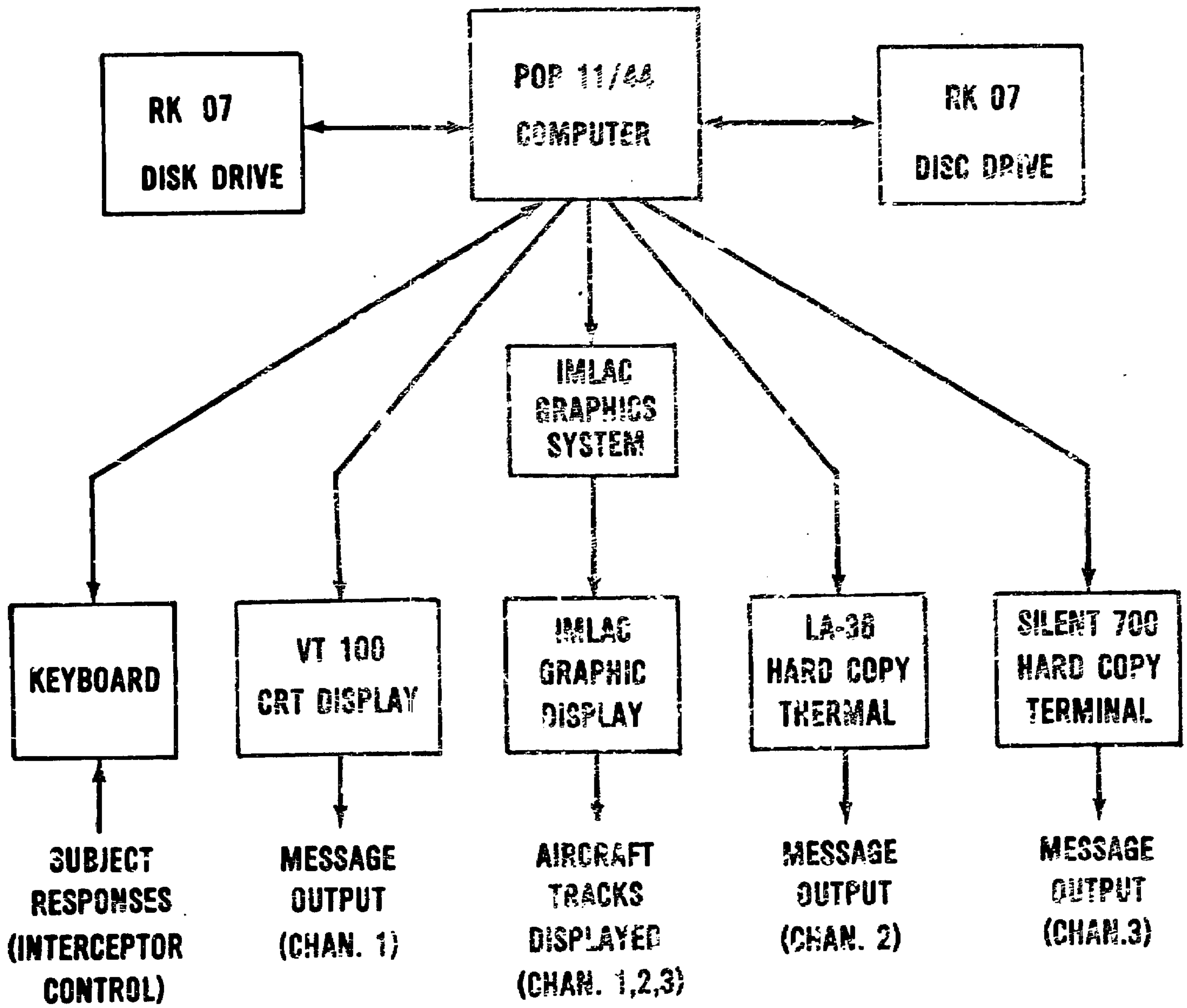


FIGURE 2. SIMULATION BLOCK DIAGRAM

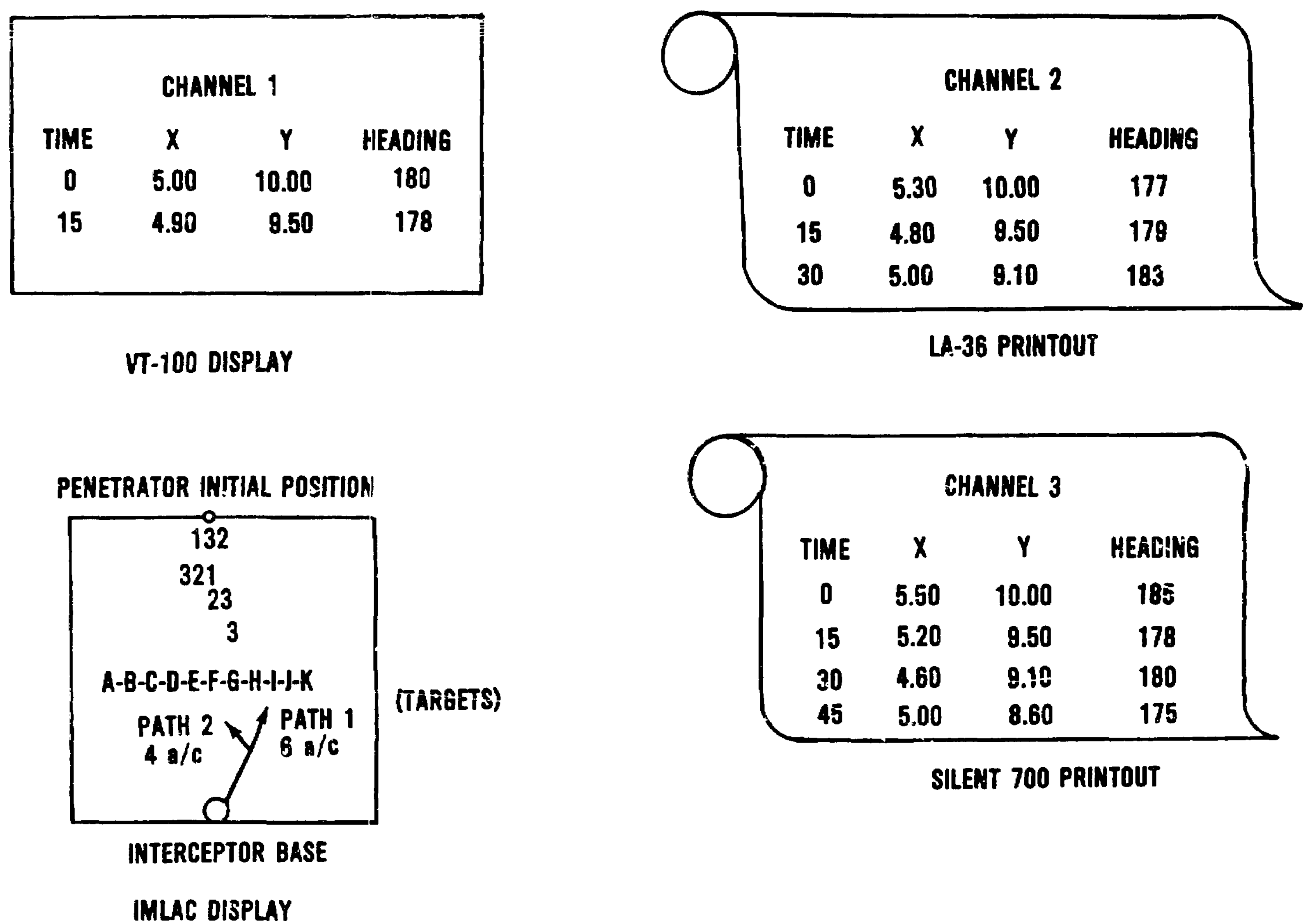


FIGURE 3. EXAMPLES OF INFORMATION PRESENTED TO THE SUBJECT.

The situation display represented an overhead, map-type view of the ADC's geographic area of responsibility. The penetrators started at the center of the top of the screen and moved towards the eleven targets (designated A to K) located on the center line of the screen. When available, the last reported penetrator position from each communication channel was indicated by displaying a 1,2, or 3 at the X-Y coordinates provided by the respective channel. The interceptor aircrafts started at the bottom center of the screen and were launched and directed towards a target by the subject. Again, all the data presented on the three communication channels were subject to the time delays and precisions previously shown in Table I.

These channel information precisions are depicted in Figure 4. The position information was plotted (after the appropriate time delay) within the precision limits indicated. For this figure, the penetrators were moving towards target F. An example presentation of the penetrator data is shown in Figure 5 for the experimental treatment T-D-J; where truth (T), deception (D), and jamming (J), have been applied to channels 1, 2, and 3, respectively. This example illustrates a typical problem faced by the subject--identification of true versus deceptive information. Finally, a depiction of an actual situation display is shown in Figure 6. In this case, channels 1 and 3 contain true data and channel 2 contains false data about the deceptive target D. The channel precisions and time delays are apparent for the penetrator data and the separation of the interceptors into three groups of 3, 5, and 2 aircraft is shown. In this case, path 1 with 3 aircraft has been incorrectly placed on target E, path 2 with 5 aircraft didn't reach the true target B in time, and path 3 with 2 aircraft didn't reach the deceptive target D in time.

SUBJECT PROCEDURE

For each experimental session, the subject was seated in the display configuration shown in Figure 7. Each session took about one hour and consisted of 16 trials, each trial lasting 150 seconds. The subject controlled 10 interceptor aircraft to counter an incoming flight of 10 penetratory aircraft. A standby message on the IMLAC signaled the beginning of each trial, followed by a five-second delay and then the presentation of the first penetrator position data. The subject used the IMLAC graphics for X-Y situation display and the video

CHANNEL	PRECISION LIMITS
1	5% ERROR
2	10% ERROR
3	15% ERROR

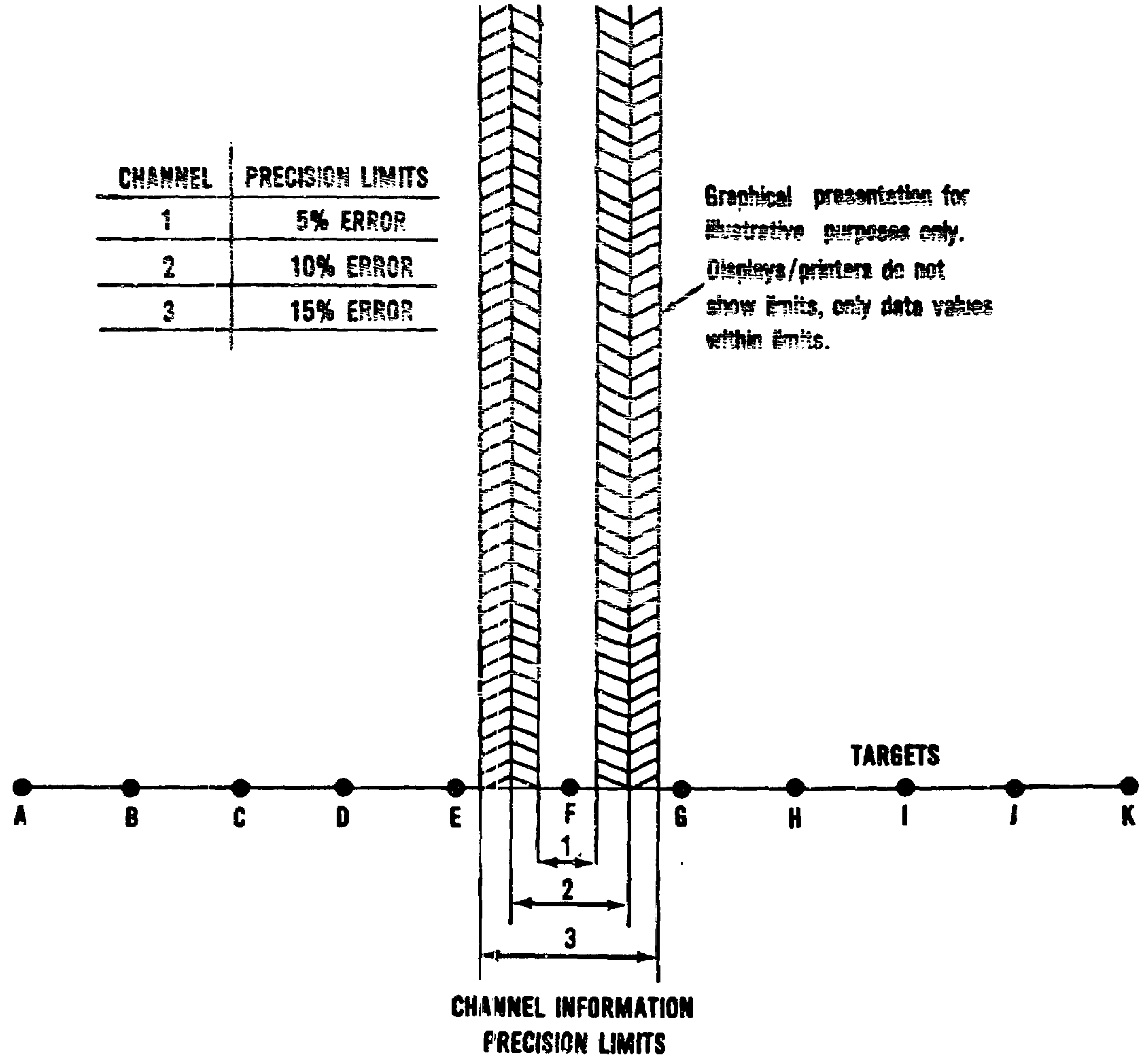
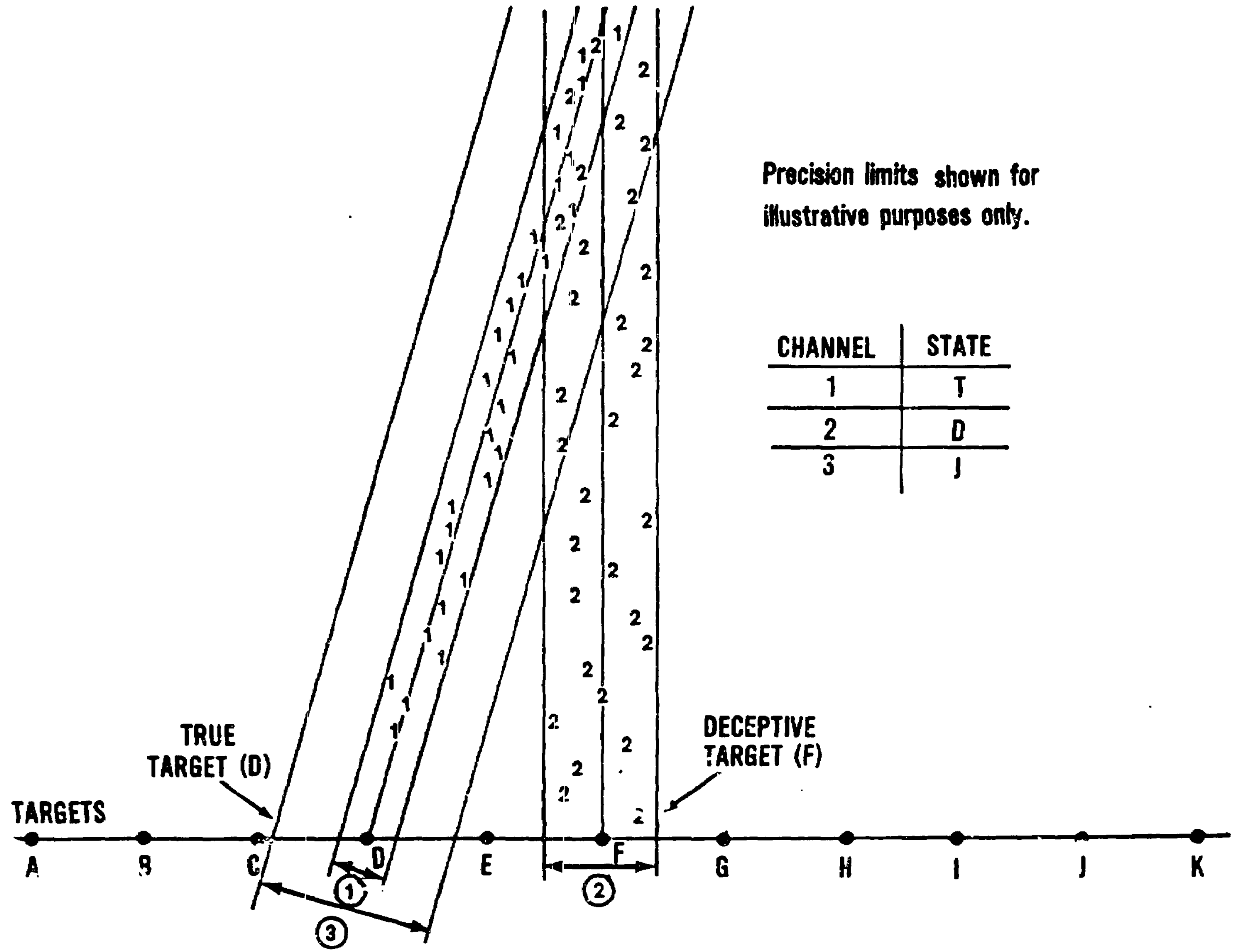


FIGURE 4. CHANNEL PRECISION CHARACTERISTICS



Precision limits shown for illustrative purposes only.

CHANNEL	STATE
1	T
2	D
3	J

FIGURE 5 EXAMPLE SITUATION DISPLAY FOR TREATMENT T-D-J.

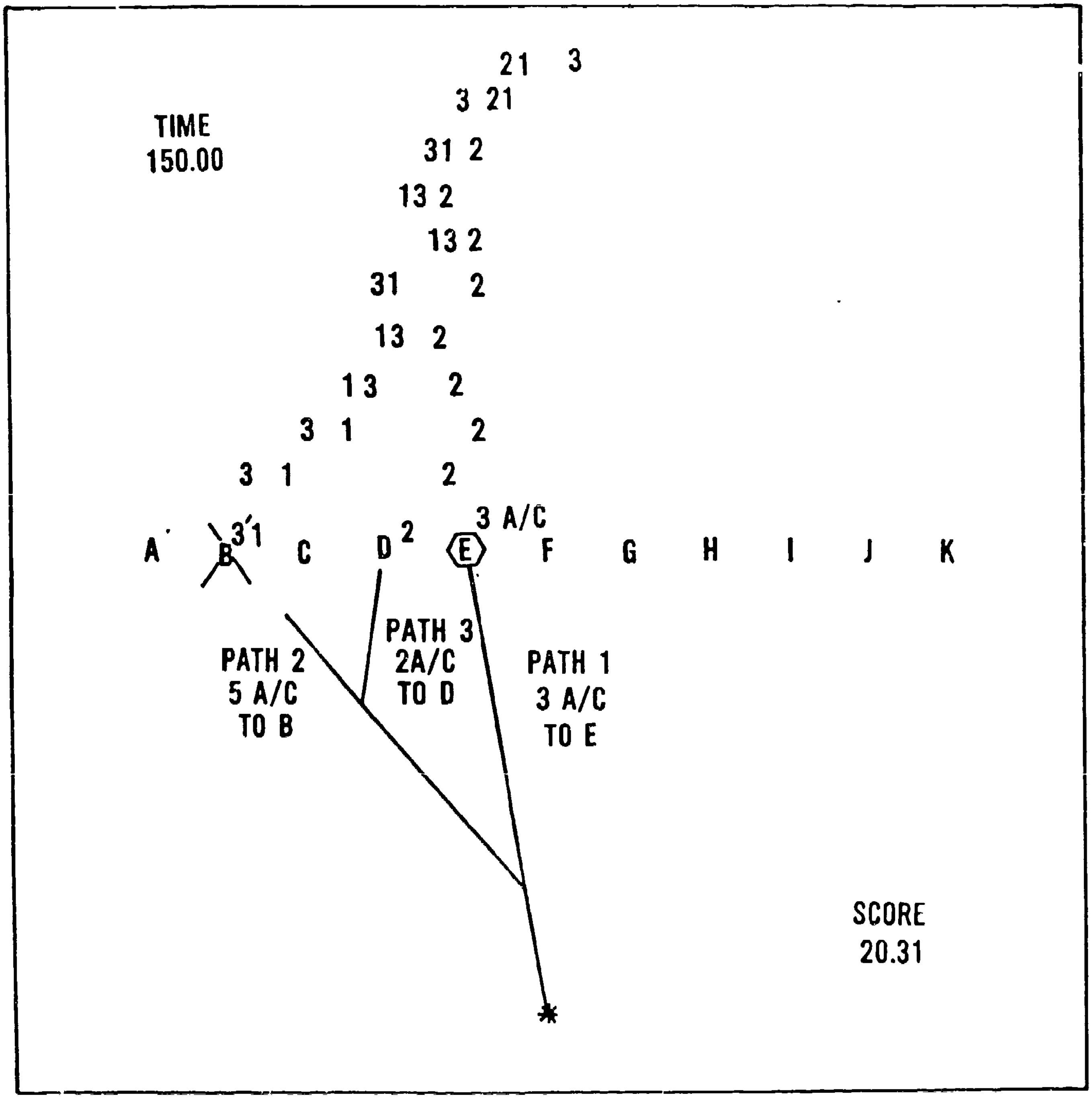


FIGURE 6. SAMPLE SITUATION DISPLAY (CONDITION TDT; TRUE TARGET B; DECEPTIVE TARGET D)

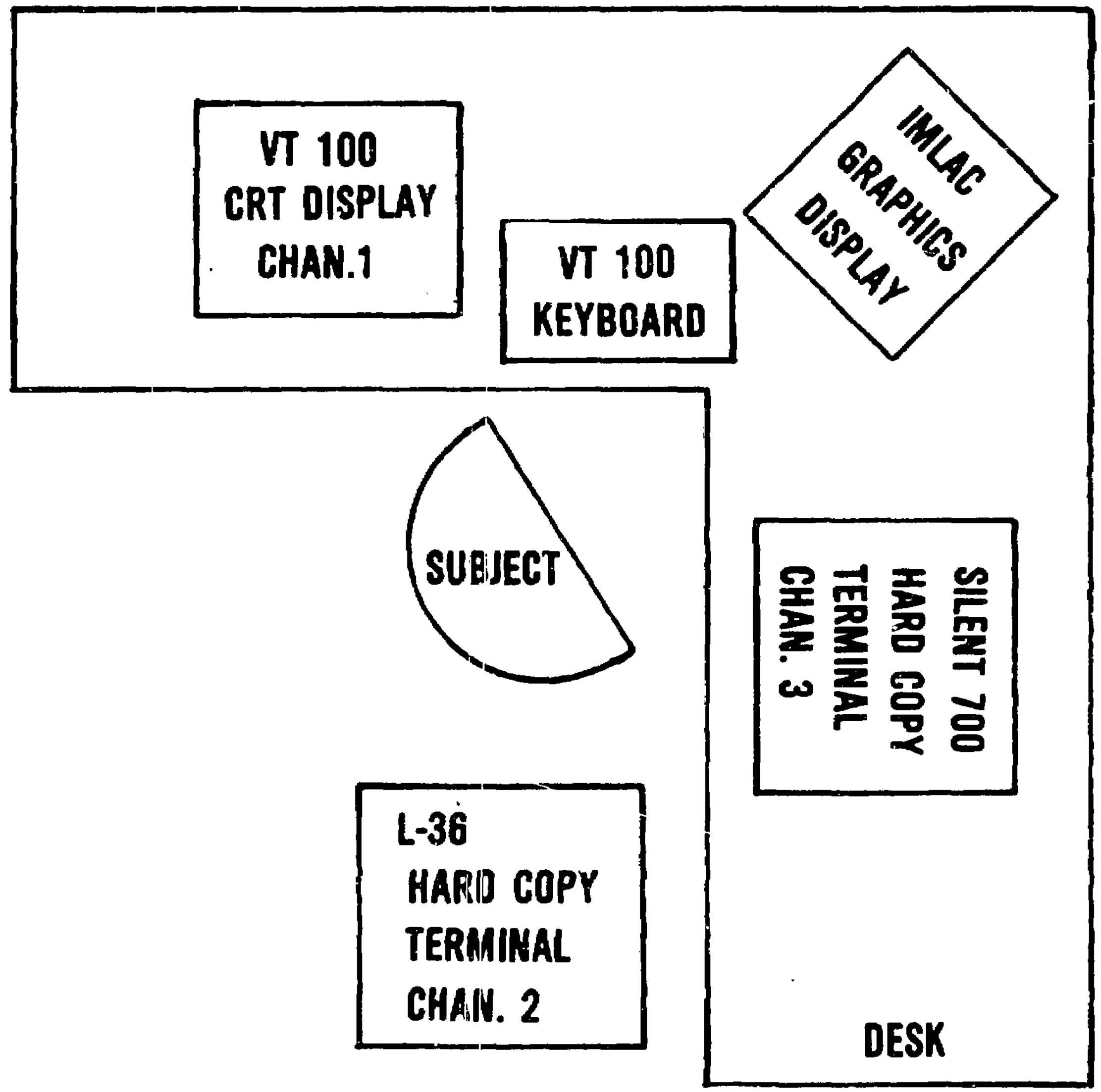


FIGURE 7. TERMINAL AND DISPLAY ARRANGEMENT

and hardcopy terminals for messages containing time, X position, Y position, and heading information. The subject then used the keyboard to direct any number of his 10 interceptors to the target area. Multiple interceptor paths were allowed so the operator could split his forces when he was uncertain about the true penetrator targets. The interceptor velocity was 1.35 times faster than the penetrator velocity to allow the subject to recover from minor incorrect decisions or a delayed launch. The subject created interceptor paths by inputting (1) a target letter (A through K) to indicate the interceptor destination and (2) the number of interceptor aircraft (1-10) to vector along the path. If a previously generated interceptor path was redirected or split, the subject also input the alphanumeric designator for the original path. At the end of each trial, the IMLAC displayed the true penetrator target and a feedback score which was proportional to the distance between the interceptors and true target at the end of the trial.

EXPERIMENT DESIGN

Two independent variables were manipulated: (a) Channel Data: truth, jamming, or deception; and (b) Channel Affected: Channel 1, 2, or 3. When truth was present on a channel, the information was presented in the manner previously discussed. When jamming was present on a channel, the channel was inactive for that entire trial so no information was provided by that channel. When deception was present on a channel, a deceptive target located two target positions away from the true target was randomly selected. For instance, if C was the true target, A or E could be selected as the deceptive target. Then information which is characteristic of the channel being deceived (see Table I) was presented to indicate the penetrators were moving towards the deceptive (false) target.

As shown in Table II, three different categories of jamming and deception were tested. A full factorial combination of (a) and (b) above was not required because several treatments are experimentally equivalent. For instance,

D-D-D = T-T-T

D-T-T = T-D-D

J-T-T = J-D-D

Since the subject's task was to isolate truth from deception by correlating at least two communication channels, multiple applications of deception are

TABLE II. EXPERIMENTAL TREATMENTS

TREATMENT	CHANNEL 1	CHANNEL 2	CHANNEL 3	JAMMING/DECEPTION CATEGORY
1	T	T	T	(1) BASELINE CASE
2	T	T	J	(2) JAM ONE CHANNEL
3	T	J	T	
4	J	T	T	
5	T	J	J	(3) JAM TWO CHANNELS
6	J	T	J	
7	J	J	T	
8	T	T	D	(4) DECEIVE ONE CHANNEL
9	T	D	T	
10	D	T	T	
11	T	D	J	(5) COMBINED JAMMING AND DECEPTION
12	T	J	D	
13	D	J	T	
14	J	D	T	
15	J	T	D	
16	D	T	J	

T= TRUTH, J= JAMMING, D= DECEPTION

equivalent to a multiple application of truth. In addition the J-J-J treatment was not used because the subject would not be presented any penetrator data.

The jamming-only treatments (2-7) were intended to determine how loss of information delays (or speeds up) decision-making and affects overall subject performance. The deception-only treatments (8-10) were intended to determine how well and when (a) false data is detected and (b) truth is correlated. The jamming/deception treatments (11-16) will produce ambiguous data on two different channels so truth isolation by correlating channels is impossible. The data from these treatments were intended to indicate which channels the subjects rely on most for truth isolation.

Developing measures of effectiveness (MOEs) for C^3CM was a primary objective of this experiment. Consequently, a variety of dependent variables were evaluated including: subject score, number of successful intercepts, number of incorrect intercepts, and number of target selection decisions. The results of the successful and incorrect intercept analyses are provided in this report.

Six subjects served as the ADC for this experiment. They included three males and three females, all drawn from an on-site subject pool of university students maintained by a support contractor. All subjects were trained until their performance stabilized, usually requiring about four 1-hour sessions. Each subject completed 8 sessions made up of all of the 16 treatments, resulting in 48 replications of each treatment (6 subjects x 8 sessions). The order of the 16 treatments and selection of targets were randomized for each session.

The feedback score was designed to encourage the subjects to try to get as close as possible to the true target even if they were running out of time and couldn't possibly make the full intercept (all 10 aircraft). A best score of 0 was possible if all 10 interceptors were at the true target before the penetrators reached it and a worst score of 100 would result if all 10 interceptors reached target F when A was the true target (or vice versa). The feedback score did have the drawback of unintentionally encouraging some of the subjects to direct the interceptor to center positions between the true and deceptive targets. This strategy resulted in a "fair" score rather than a good or bad score which would have been achieved if the right or wrong targets were selected, respectively.

SECTION 3

RESULTS AND DISCUSSION

An analysis of variance (ANOVA) was first performed on all the 16 experimental conditions, grouped into the 5 jamming/deception (J/D) categories (see Table II) to determine which general type of countermeasure significantly affected subject performance. The number of successful intercepts, defined as the number of interceptor aircraft to reach the true target before the penetrator aircraft, was chosen as the dependent measure for this analysis. ANOVAs were then performed on categories 2, 3, 4, and 5 to determine any differences between the conditions within each category. An additional ANOVA looked specifically at the number of incorrect intercepts for the six conditions within J/D category 5 to determine how combined jamming and deception influenced the subjects' decisions to select incorrect targets. In this case, number of incorrect intercepts are defined as the number of interceptor aircraft to reach any target other than the true target before the end of the trial.

The dependent measures and jamming/deception categories for each of the ANOVAs are summarized in Table III. Source tables for these ANOVAs are located in Appendix A. In addition, a short description of the decision making strategies used by the subjects is provided in this section.

SUCCESSFUL INTERCEPTS

The successful intercepts shown in Figure 8 for category 1 (all truth condition) establish a baseline performance level. For what should be the optimum condition, the subjects averaged about six intercepts or a success rate of about 60%. This indicates the basic task of correlating true information from three sources to reach a decision was not excessively easy. The subjects were able to direct the interceptors to reach the target line about 80% of the time, indicating 20% of the interceptors didn't reach a target and 20% were sent to an incorrect target. This implies the subject performance was limited by both the time stress of the scenario and the precision and timeliness limitations of the three channels.

Comparison of the ANOVA results from category 1 with the successful intercepts for the average of the conditions within categories 2 and 3 indicates

TABLE III

SUMMARY OF ANALYSIS OF VARIANCE

ANOVA TITLE	DEPENDENT MEASURE	JAMMING/DECEPTION CATEGORY (NO.)
SAS 16-SI	NUMBER OF SUCCESSFUL INTERCEPTS	ALL (1-5)
SAS 24-SI	" " " "	JAM ONE CHANNEL (2) DECEIVE ONE CHANNEL (4)
SAS 3-SI	" " " "	JAM TWO CHANNELS (3)
SAS 5-FI	" " " "	COMBINED JAMMING & DECPTION (5)
SAS 5-SI	" "FAILED "	COMBINED JAMMING & DECEPTION (5)

NOTE: SEE APPENDIX A FOR SOURCE TABLES

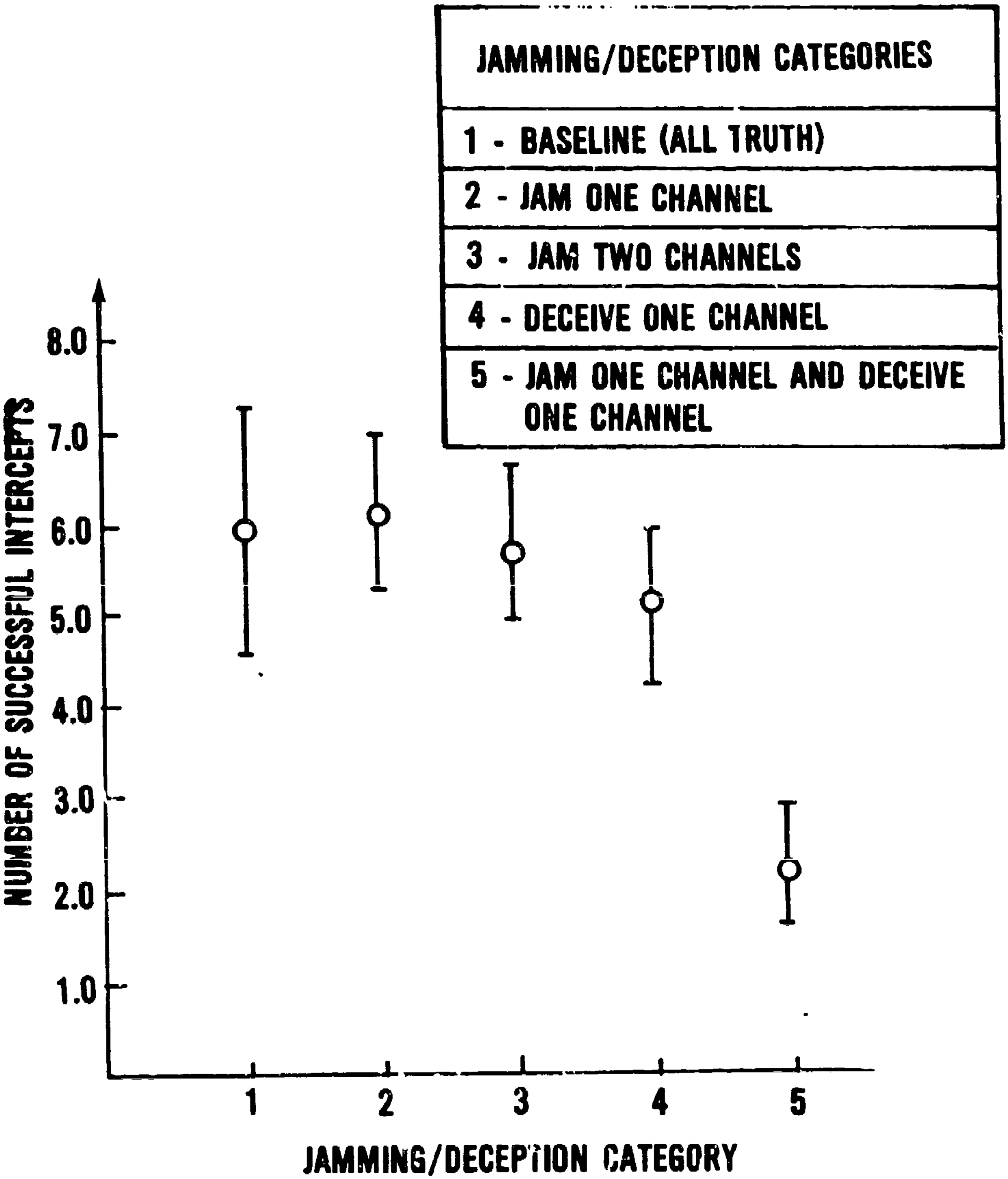


FIGURE 8. SUCCESSFUL INTERCEPTS FOR THE JAMMING/DECEPTION CATEGORIES; MEANS AND 95% CONFIDENCE INTERVALS

there were no significant differences when one or two channels were jammed. This result implies the subjects could achieve at least baseline performance with only one or two operative information sources. Multiple channels are obviously important for assuring the task can be accomplished when one or more channels become inoperative. Consequently, the category 2 and 3 results illustrate the importance of information redundancy. It is also important to notice performance did not improve when less information was presented. This indicates the amount of data available to the subject was not burdensome for this scenario.

Similar results were obtained for category 4. Again, no significant change from baseline occurred when deception was applied to only one channel. This result indicates detection and elimination of deceptive information is generally not difficult if two channels are still available for truth correlation. This misleading type of deception does have the potential though of becoming significant if applied at a more critical point in time for a different scenario.

As expected, category 5 results varied significantly from the rest. For these six conditions, one channel was jammed, one contained truth, and the remaining channel contained false information. This type of countermeasure application resulted in an ambiguous situation...a 50-50 chance of success. Consequently, the average performance for this category dropped by about 50% from the baseline. In terms of degrading the decision maker, this jamming/deception technique is optimal.

For this analysis across all 16 conditions (SAS16-SI), there were 2 significant main effects. One was the target variable, and, as shown in Figure 9 when target B was the true target, the average number of successful intercepts obtained was significantly lower than the number for targets D and E. The tendency to have degraded performance when outer targets were selected was probably caused by the subjects' perception that the outer targets took longer to reach than the inner targts. In reality, the interceptor speed was always adjusted to 135% of the penetrator speed, based on the location of the true target. But any hesitation to send interceptors to an outer target because the information may be false can be expected to reduce the number of intercepts. This fact has real world significance though, because an air defense commander would have to consider the risk of defending an outer region and consequently

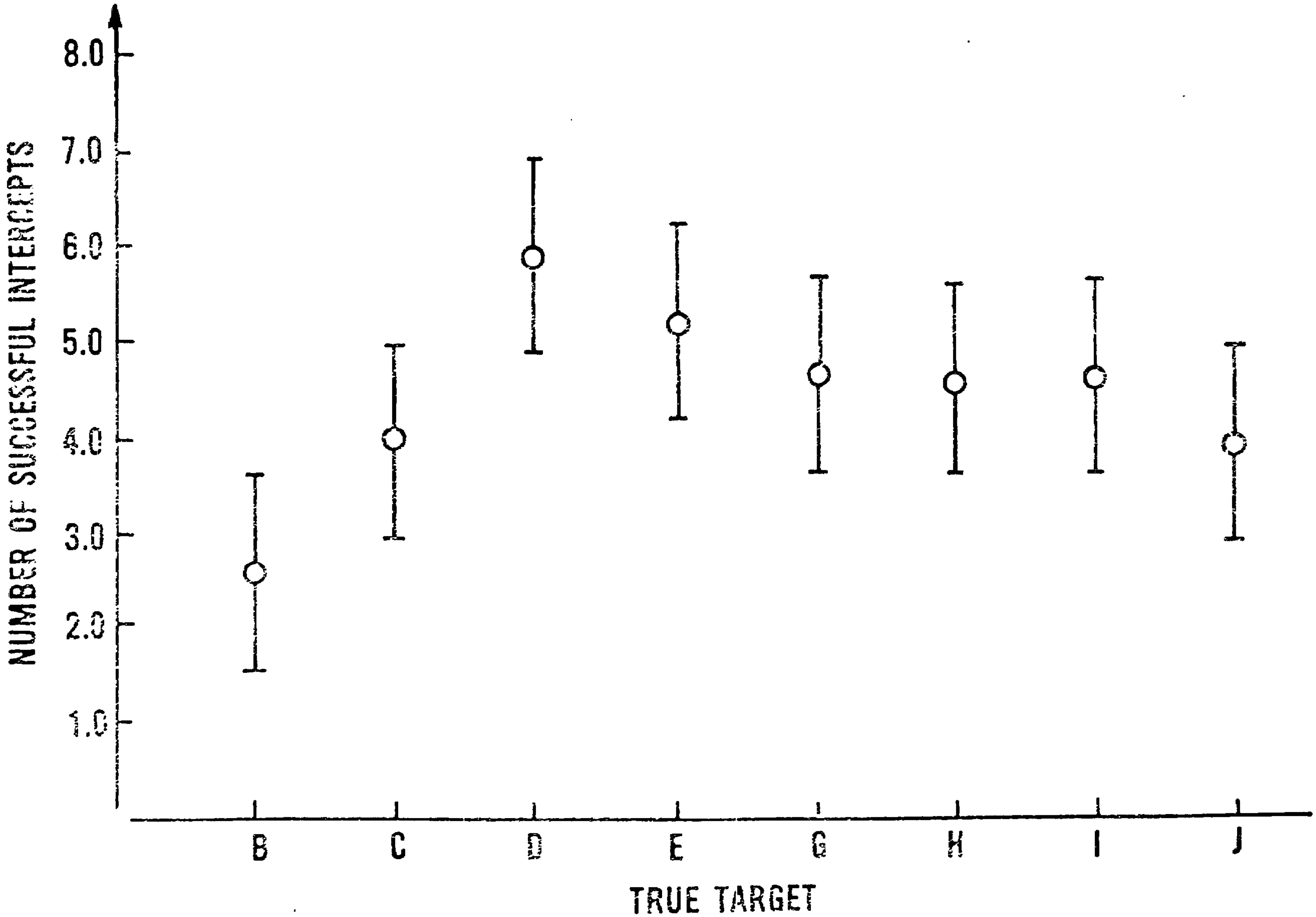


FIGURE 9. SUCCESSFUL INTERCEPTS AS A FUNCTION OF TRUE TARGET;
MEANS AND 95% CONFIDENCE INTERVALS

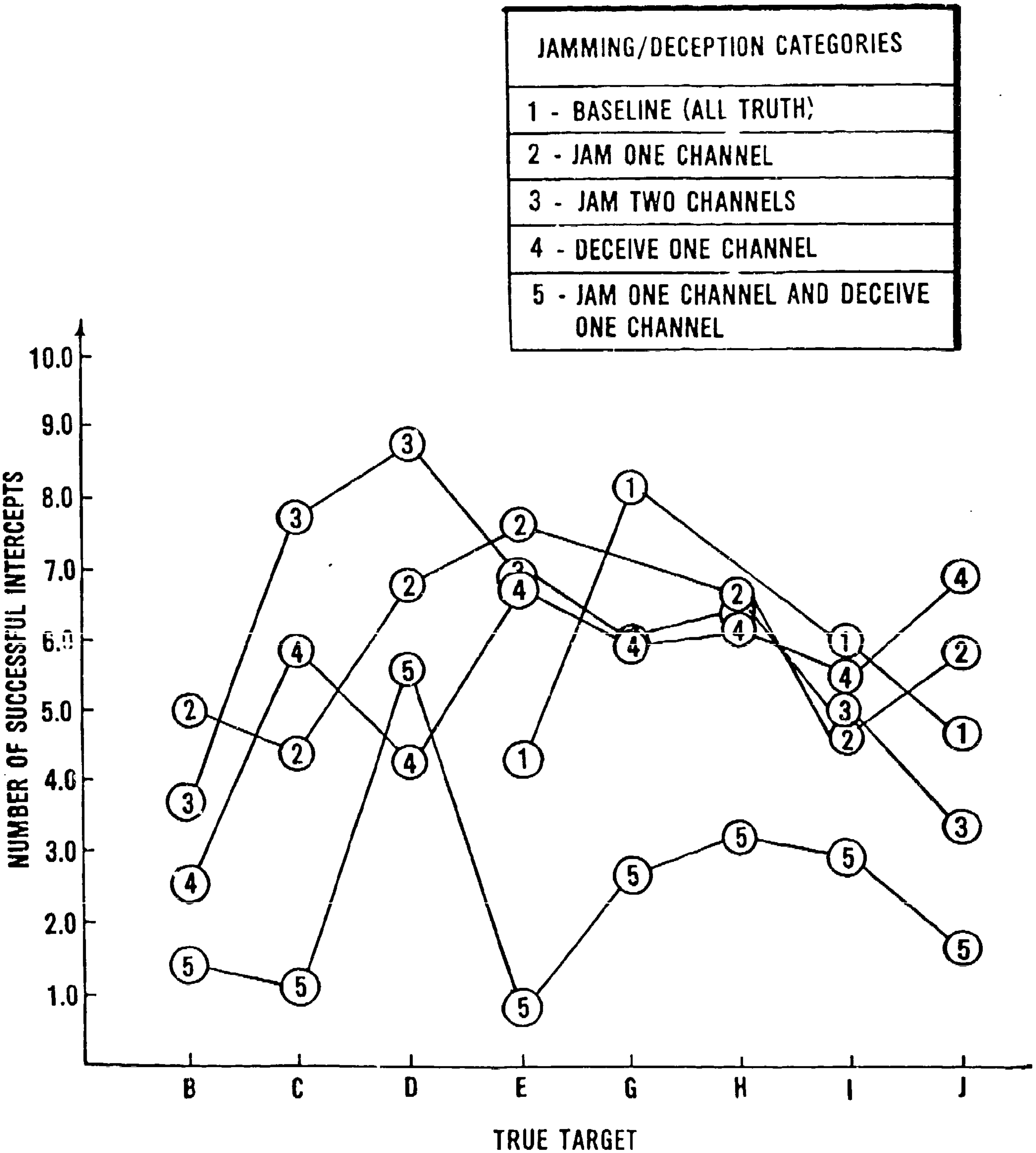


FIGURE 10. MEAN SUCCESSFUL INTERCEPTS AS A FUNCTION OF JAMMING/DECEPTION CATEGORY AND TRUE TARGET

increasing the vulnerability of the remaining regions. The effect of target also interacted with the J/D category variable, as shown in Figure 10. It should be noted that use of a random target selection technique resulted in unequal numbers of J/D category and target combinations. But again, for most of the J/D categories, subject performance tended to be enhanced when the true target was centrally located. The second main effect was the subject variable. As shown in Figure 11, the average number of successful intercepts obtained for subjects 3 and 6 was significantly lower than the number for subjects 2 and 4.

A second ANOVA (SAS24-SI) examined successful intercepts when jamming or deception was applied to a single channel. As shown in Figure 12, jamming channel 3 reduced intercepts to a level comparable to all three of the deception conditions. Apparently the timeliness characteristic of the channels was more important than the precision characteristic. Removal of channel 1 data (condition JTT) resulted in about seven intercepts which was slightly higher (but not statistically significant) than the baseline result of about six intercepts. This result implies that jamming the less timely channels could have an adverse effect. Realistically speaking, this result is desirable since the more highly aggregated information channels tend to be less susceptible to jamming. The lack of significant differences between the deception conditions indicates it could be unimportant how misleading deception is applied (which channel) since the commander can use alternate sources to separate truth from deception. It is important to note, though, that any application of deception resulted in performance degraded down to the best application of jamming (condition TTJ).

A third ANOVA (SAS3-SI) tested for significant effects in J/D category 3 when two channels were jammed, leaving one true channel. For this category, the successful intercept results for the three conditions did not vary significantly, indicating the subject performance remained around the baseline level with any single channel available on which to base a decision. There were, however, two effects that were significantly different. The main effect of target selection was significant. As shown in Figure 13, when the outer targets (B and J) were the true targets, subject performance was degraded. Again, this was probably caused by the subjects' reluctance to commit interceptors to an outer region early in the trial. The main effect of subject variables, as seen in Figure 14, shows the average number of successful intercepts obtained for subject 6 was significantly lower than the number for subject 2. The subject

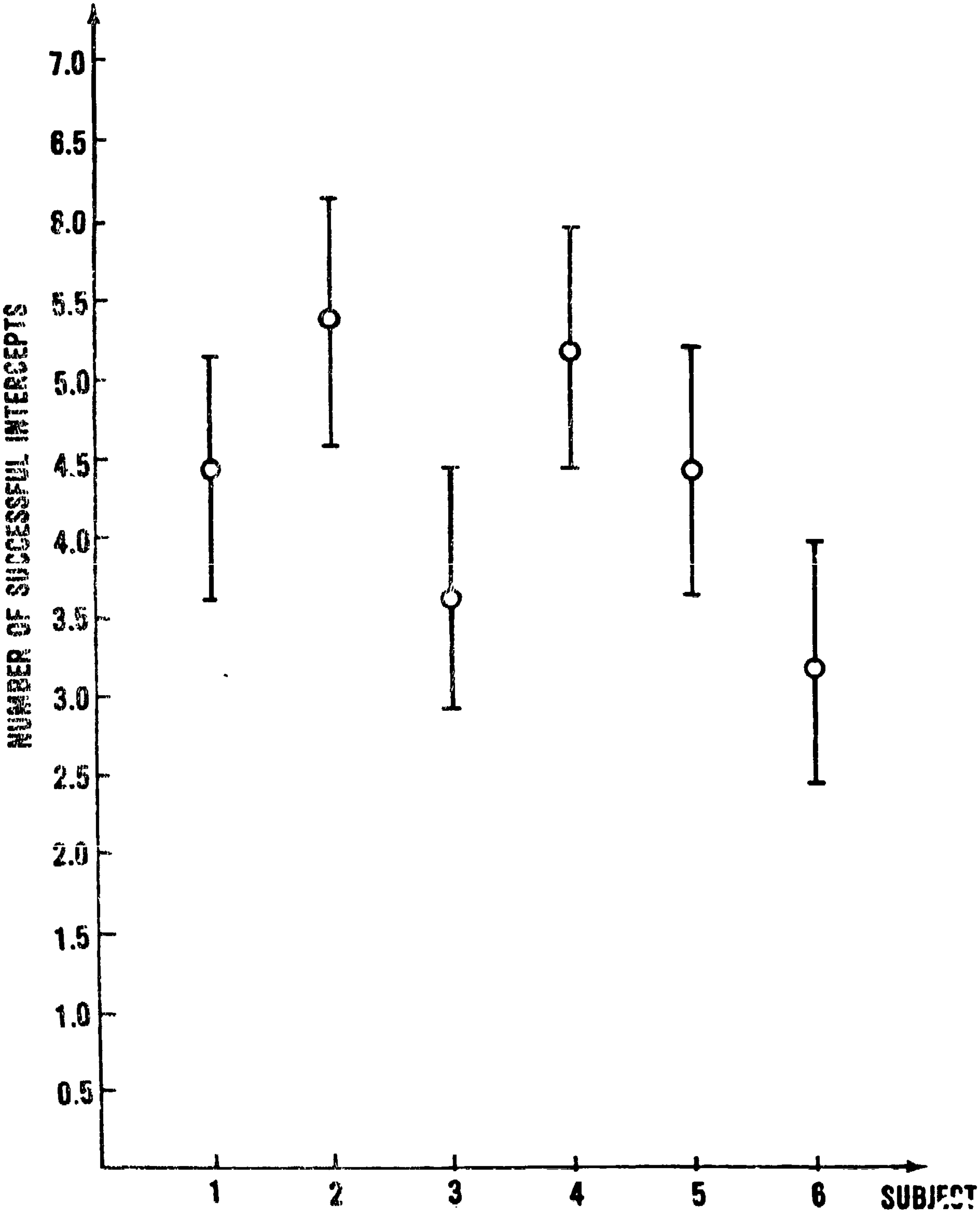


FIGURE 11. SUCCESSFUL INTERCEPTS AS A FUNCTION OF SUBJECTS; MEANS AND 95% CONFIDENCE INTERVALS

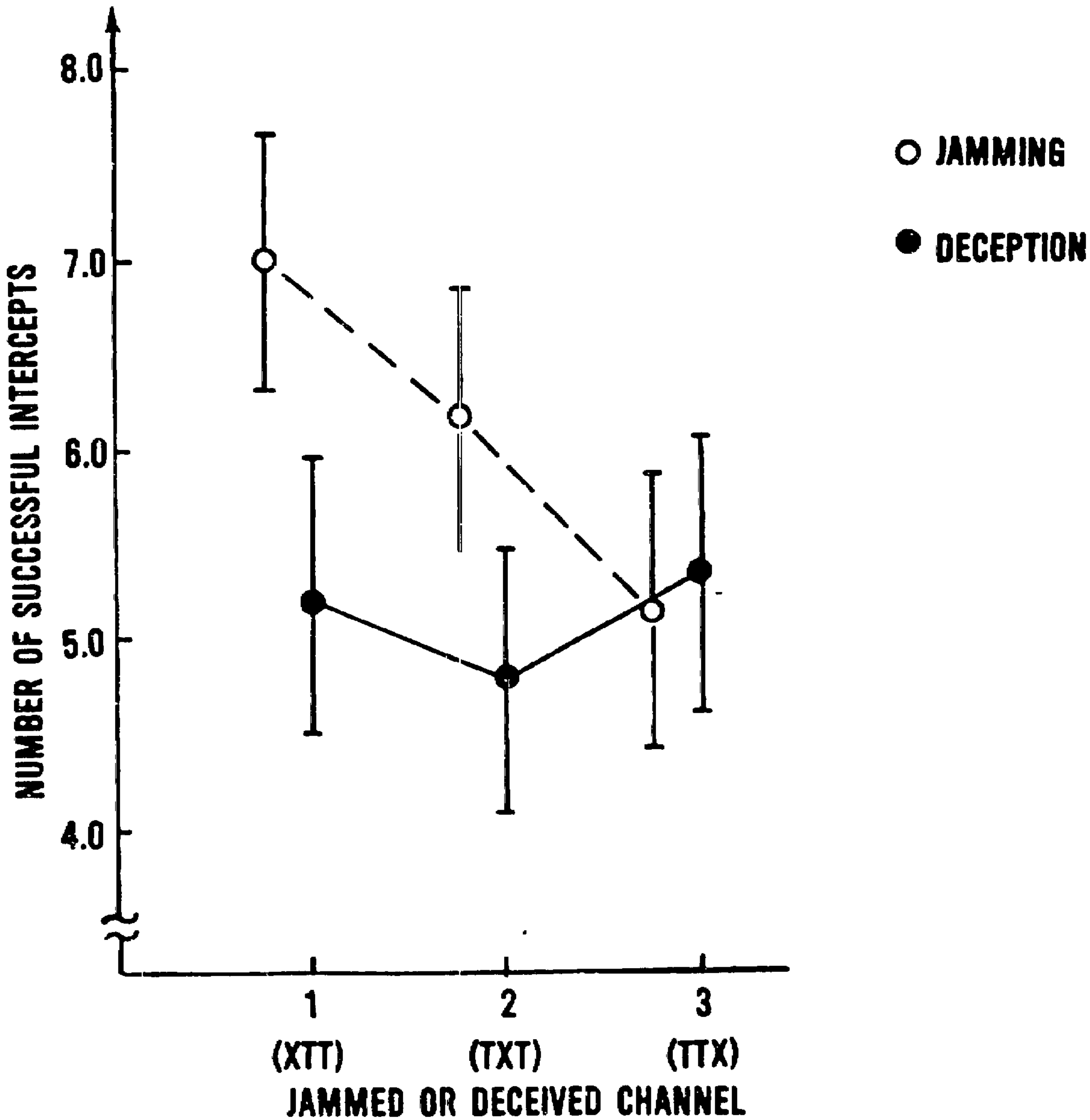


FIGURE 12. SUCCESSFUL INTERCEPTS WHEN JAMMING OR DECEPTION IS APPLIED TO A SINGLE CHANNEL; MEANS AND 95% CONFIDENCE INTERVALS

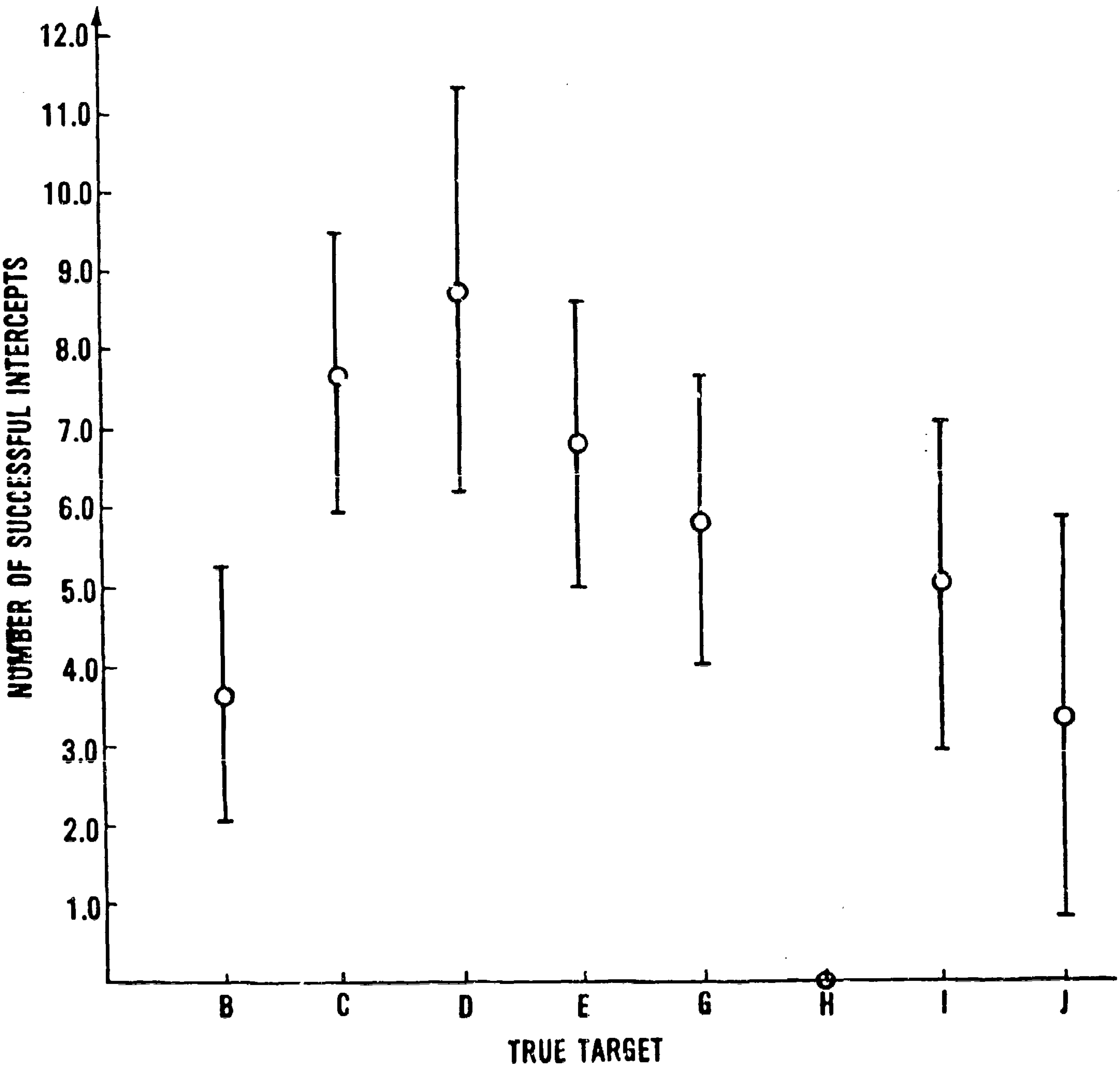


FIGURE 13. SUCCESSFUL INTERCEPTS AS A FUNCTION OF TRUE TARGET FOR J/D CATEGORY 3; MEANS AND 95% CONFIDENCE VS INTERVALS

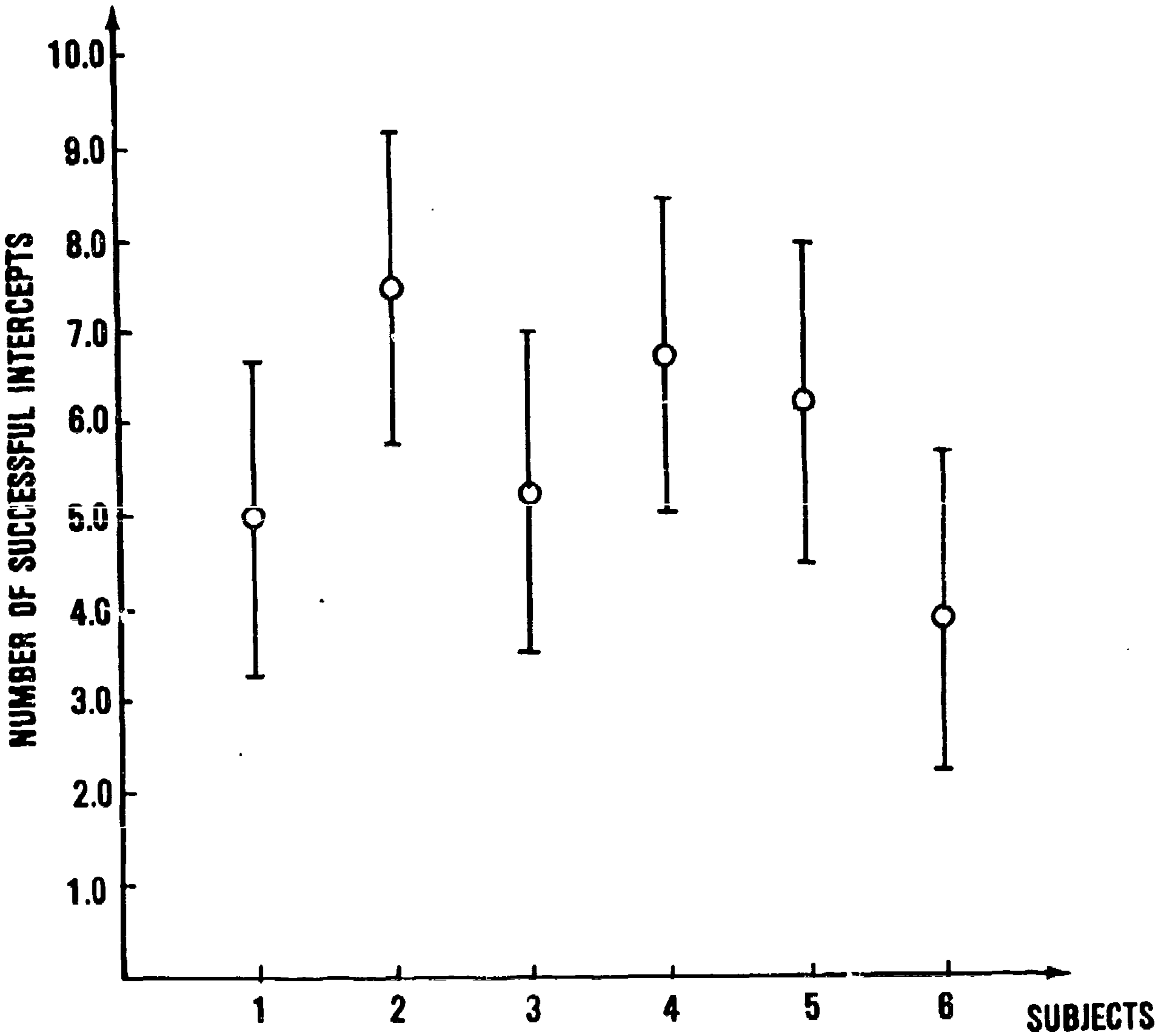


FIGURE 14 SUCCESSFUL INTERCEPTS AS A FUNCTION OF SUBJECTS FOR J/D CATEGORY 3; MEANS AND 95% CONFIDENCE INTERVALS

difference was probably due to individual strategies used during the simulation. Strategy differences will be discussed later in the subject strategy section.

The last ANOVA performed on the successful intercept metric (SAS5-SI) also resulted in the target selection variable as the only significant source of variation. In this case, target D was easier to intercept, but surprisingly, the adjacent target E resulted in reduced intercepts (Figure 15). Besides this anomaly, the outer targets followed the same pattern of inducing poorer subject performance.

INCORRECT INTERCEPTS

Despite the fact that the successful intercept results between the six conditions within this category did not vary significantly, the tendency of the subjects to select incorrect targets was analyzed to determine the optimum combination of jamming and deception.

An analysis of the number of incorrect intercepts determined how often the subjects vectored their interceptors to an incorrect target before the penetrators reached the true target. This analysis (SAS5-FI) did not account for the interceptors that didn't reach the target line in time so, in a sense, this metric is a measure of how well the subjects were either deceived into selecting the false target or resorted to selecting a target other than the true target. The latter case often occurred for J/D category 5, especially in the last few sessions, when some of the subjects selected the target in between the true and false targets. This strategy was used to obtain a "fair" feedback score but the final result still remains--that is, the subjects were adequately deceived.

As shown in Figure 16, the number of incorrect intercepts for condition DTJ was significantly higher than most of the other five conditions. For this condition, the most timely data was jammed and the most precise data was false, leaving truth available only on the mediocre channel 2. This condition probably represents the worst case condition for this experiment and the results verify this hypothesis. If extremely timely information is not available to provide an initial interceptor launch direction, the subjects are immediately time stressed to reach the target. With deception and truth on channels 1 and 2, respectively, the presence of an ambiguity was probably not detected until late in the trial because of overlapping position data characteristics of the

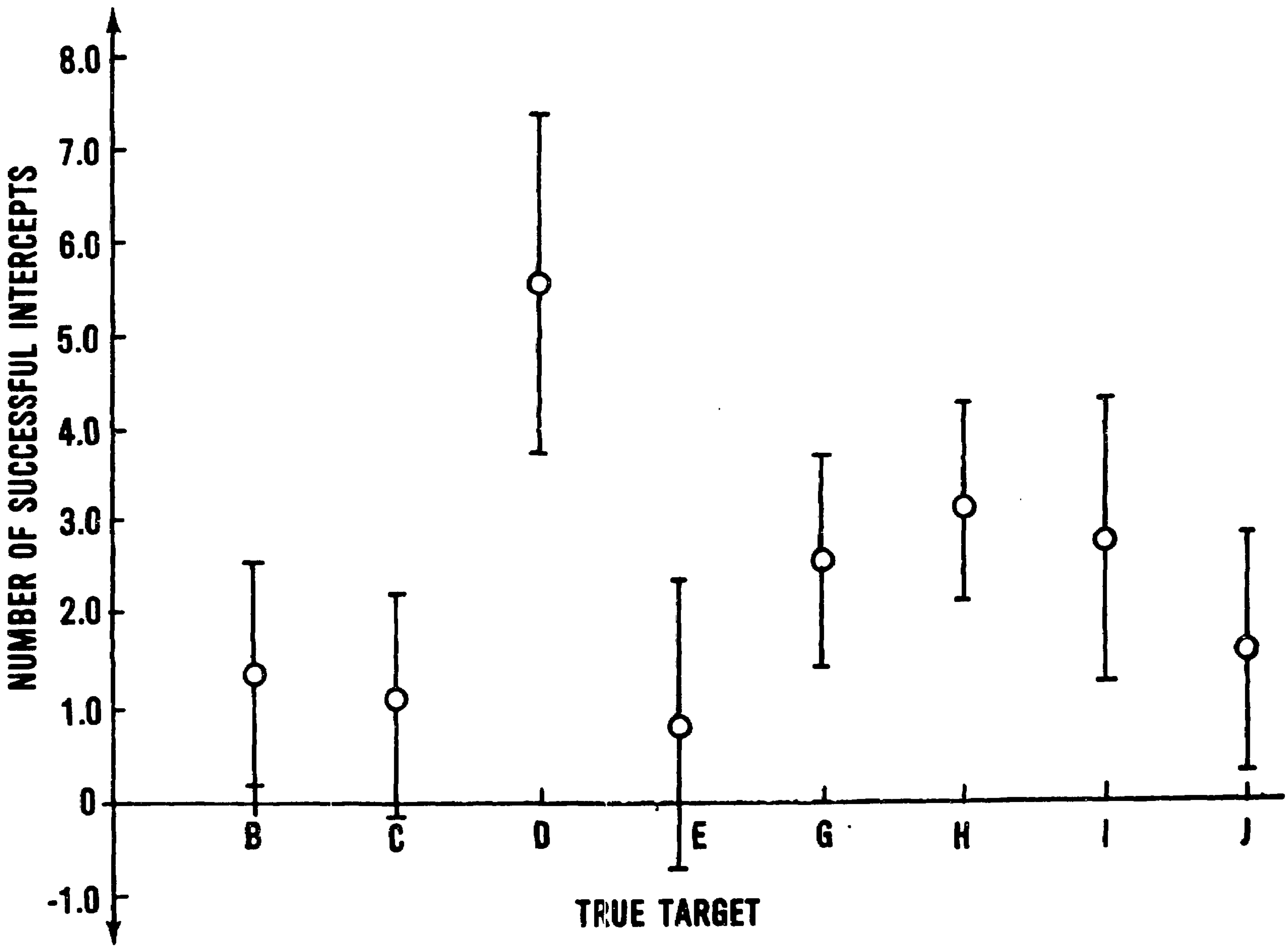


FIGURE 15. SUCCESSFUL INTERCEPTS AS A FUNCTION OF TRUE TARGET FOR J/D CATEGORY 5; MEANS AND 95% CONFIDENCE INTERVALS

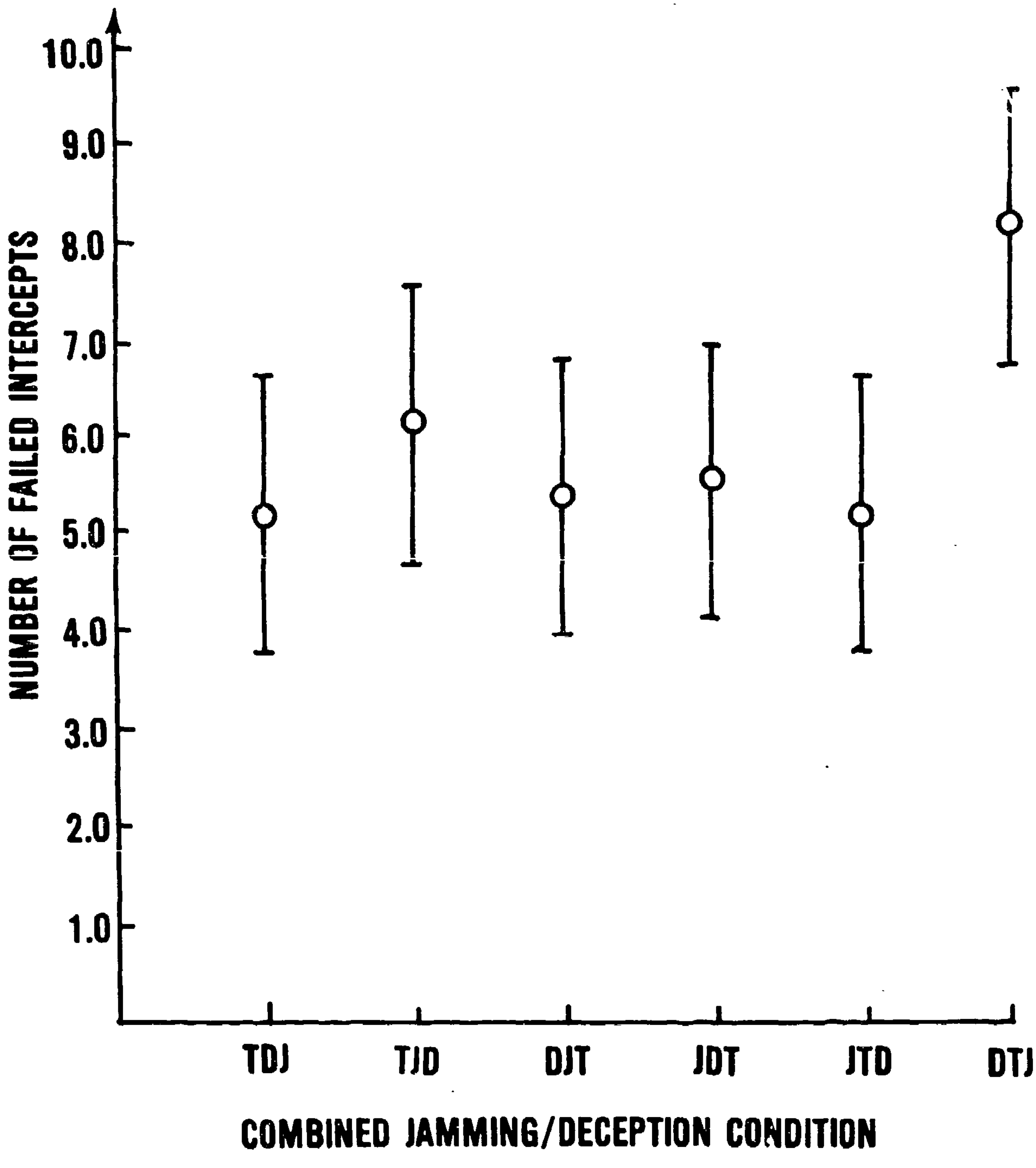


FIGURE 16. FAILED INTERCEPTS FOR THE COMBINED JAMMING/DECEPTION CONDITIONS; MEANS AND 95% CONFIDENCE INTERVALS

precision limits of the channels. Consequently, the subjects were faced with a time-stressed decision and a subtle ambiguity in the data, resulting in a selection of the most accurate (but false) channel 1 or the neutral target located between the true and false target.

The tendency for the use of the outer targets to result in lower subject performance holds true for this analysis as shown in Figure 17. Faced with an ambiguous situation, the subjects' risk in going with the outer targets is substantially increased. Again, target E tended to deviate from this trend but the confidence intervals shown indicate the results for target E were not statistically significant from either the harder targets (B,C,I, and J) or the easier targets (D,G, and H).

SUBJECT STRATEGIES

Two analyses, SAS16-SI and SAS3-SI, did show significant differences in the performance results between the six subjects. A short discussion of the strategies they employed might provide some insights into possible human vulnerabilities to jamming and deception. The experimental scenario was designed to give the subjects a large degree of freedom in how they could intercept the penetrators. Any path or number of paths (up to 10) could be taken to the target line. The availability of 10 interceptors to counter 10 penetrators was chosen to induce the subjects to divide their forces to reflect their confidence in their decision. The number of decisions which includes target selections, path creations and redirections, was also uncontrolled. Despite all this flexibility, some consistent strategies emerged.

The subjects usually tended to wait around 15 to 30 seconds to launch the interceptors, indicating they waited until several data points were presented. For almost all of the trials, the entire group of 10 interceptors were launched simultaneously along a single path. There were a few cases of generation of two initial groups of five. These tendencies to delay a short time and then launch all the available interceptors at once indicate the subjects didn't want to risk picking a grossly incorrect target. On the other hand, they rarely made the mistake of leaving interceptors at the base too long and consequently missing an intercept because of indecisiveness.

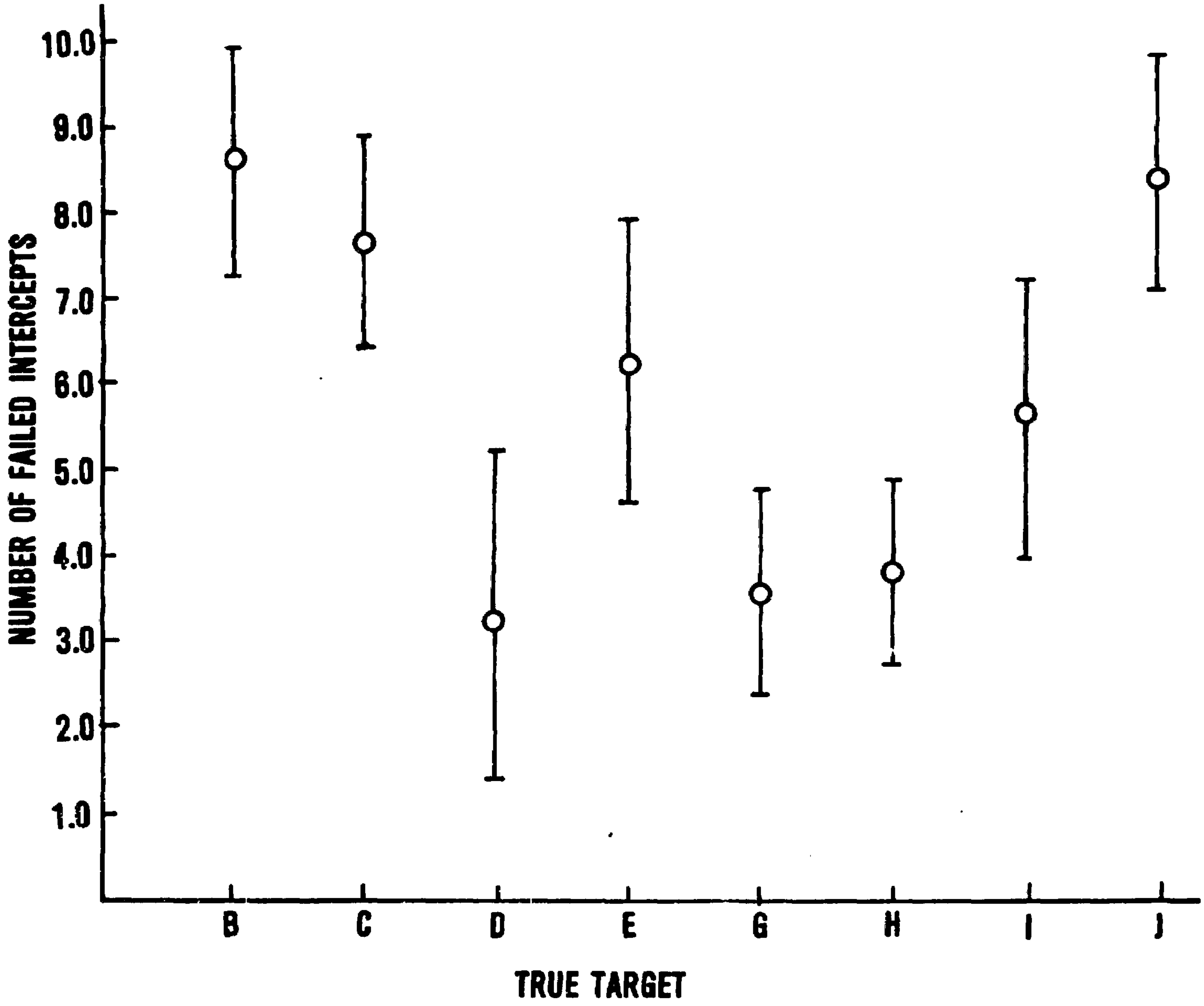


FIGURE 17. FAILED INTERCEPTS AS A FUNCTION OF TRUE TARGET FOR J/D CATEGORY 5; MEANS AND 95% CONFIDENCE INTERVALS

When this initial launch was made, four of the subjects went towards their first guess of the correct target while the other two subjects usually started towards the center target (F). This latter strategy allowed these two subjects to delay their first target selection until more data was available, perhaps resulting in slightly more flexibility if a major redirection was required.

The two subjects that usually started towards target F did differ in their second decision strategy. One almost always kept her group of 10 interceptors together while the other often split hers into groups of 5. In fact, the other 4 subjects also mostly used a single group of 10 but often made a 5 and 5 split. There were a few rare cases of splits of seven and three but the five and five split was definitely preferred when the subjects decided to have two separate paths. This strategy probably indicates the relative confidence the subjects had in the information sources. Since each channel was equally susceptible to countermeasures, there was little reason to place more confidence in one channel versus any other. Splitting the interceptors equally allowed the subjects to move towards multiple targets in hopes of at least a partial intercept until more data was available to base a final decision on. There was evidence the five and five split was used to cover two targets when the channel precision characteristics prevented the subjects from clearly determining the penetrator heading and also when the presence of deception resulted in two possible target selections.

In a more realistic scenario, the channels would not be equally susceptible to the countermeasures, probably resulting in more variations in how interceptor resources would be divided. The predominance of the strategy where all 10 interceptors were kept together should be kept in mind though because this strategy might also predominate in the real world. In this case, the group of 10 would be directed towards the target indicated by the highest-confidence channel or perhaps stated more correctly, the channel with the least uncertainty.

SECTION 4

CONCLUSIONS

For the baseline condition (TTT), when truth was presented on all three channels, the subjects averaged about six successful intercepts or a success rate of about 60%. This indicates the experiment scenario was difficult enough to result in degraded performance under the best of conditions. The subjects' performance was degraded by both the precision and timeliness characteristics of the three channels.

Jamming one or two channels or deceiving one channel did not significantly change the number of successful intercepts indicating the information redundancy was adequate to maintain the baseline level of performance. When compared to jamming channel one (JTT), successful intercepts were significantly reduced when channel three was jammed (TTJ). This result implies the timeliness of the data was more important than the precision of the data.

The most dramatic performance reduction occurred when combined jamming and deception were applied. When confronted with this ambiguous situation (e.g., TJD), the subjects had at best a 50-50 chance of success. The most deceptive condition was DTJ when channel 1 was deceived and 3 was jammed, resulting in the largest number of incorrect intercepts (incorrect target selected). Consequently, denying the most timely data by jamming channel 3 and deceiving the most precise channel 1 was the optimal countermeasure. When combined jamming and deception was present, the subjects often resorted to selecting the "neutral" target located between the true and deceptive targets.

For almost every condition, when the outer targets were the true targets, subject performance was degraded, indicating the subjects were reluctant to send interceptors to their outer regions of responsibility. Making this decision in error was perceived to be less recoverable and more risky than incorrectly selecting an inner target.

The subjects used several distinct strategies and some of their resultant performance did vary significantly. There were tendencies to: (1) delay the initial interceptor launch until several data points were available; (2) launch all 10 interceptors at once; and (3) keep the interceptors together in a single group of 10 all the way to the target. Several subjects often split the interceptors into two groups of five to cover multiple targets when the channel

precision characteristics or the presence of deception made the true target difficult to discern. It is possible that this five and five split represents the subjects' confidences in the different information sources.

APPENDIX

ANALYSIS OF VARIANCE SOURCE TABLES

TABLE IV

ANALYSIS OF VARIANCE RESULTS FOR SECTION 3 (RESULTS AND DISCUSSION)
MEASURING EFFECTS USING SUCCESSFUL INTERCEPTS AS A DEPENDENT VARIABLE (SAS16-SI)

Source	Error	df (Source,Error)	MS (Effect)	MS (Error)	F-Stat	PR(f)	% Var
J/D Category	Source x Subject	4,20	428.39	22.57	18.98	0.0001	9.74
Target	Source x Subject	7,35	58.59	23.16	2.53	0.0324	2.33
J/D Category x Target	Source x Subject	22,110	42.56	16.50	2.58	0.0006	5.32
Subject	within cell	5,563	116.98	18.49	6.26	0.0001	3.30

TABLE V

ANALYSIS OF VARIANCE RESULTS FOR SECTION 3 (RESULTS AND DISCUSSION)
MEASURING EFFECTS USING SUCCESSFUL INTERCEPTS AS A DEPENDENT VARIABLE (SAS24-SI)

Source	Error	df (Source, Error)	MS (Effect)	MS (Error)	F-Stat	PR(f)	% Var
J/D Category	Source x Subject	1,5	42.89	36.73	1.17	0.3293	0.66
Disrupted Information Channel	Source x Subject	2,10	5.49	20.62	0.27	0.7715	0.17
Target	Source x Subject	7,35	23.93	18.82	1.27	0.2927	2.57
J/D Category x Disrupted Information Channel	Source x Subject	2,10	16.67	4.60	3.62	0.0656	0.51
J/D Category x Target	Source x Subject	6,29	21.48	10.75	2.00	0.0984	1.98
Disrupted Information Channel x Target	Source x Subject	10,49	13.46	25.75	0.52	0.8656	2.07
Subject	within cell	5,112	19.95	20.96	0.95	0.4517	1.53

TABLE VI

ANALYSIS OF VARIANCE RESULTS FOR SECTION 3 (RESULTS AND DISCUSSION)
MEASURING EFFECTS USING SUCCESSFUL INTERCEPTS AS A DEPENDENT VARIABLE (SAS3-SI)

Source	Error	df (Source,Error)	MS (Effect)	MS (Error)	F-Stat	PR(f)	% Var
Disrupted Information Channel	Source x Subject	2,10	8.83	37.87	0.23	0.7963	0.52
Target	Source x Subject	6,30	80.26	18.91	4.25	0.0033	14.14
Subject	within cell	5,83	38.87	17.42	2.23	0.0581	5.71

TABLE VII

ANALYSIS OF VARIANCE RESULTS FOR SECTION 3 (RESULTS AND DISCUSSION)
MEASURING EFFECTS USING SUCCESSFUL INTERCEPTS AS A DEPENDENT VARIABLE (SAS5-SI)

Source	Error	df (Source,Error)	MS (Effect)	MS (Error)	F-Stat	PR(f)	% Var
Disrupted Information Channel	Source x Subject	5,25	17.38	14.74	1.18	0.3473	1.94
Target	Source x Subject	7,35	36.02	14.14	2.55	0.0314	5.64
Subject	within cell	5,191	9.18	13.63	0.67	0.6464	1.03

TABLE VIII

ANALYSIS OF VARIANCE RESULTS FOR SECTION 3 (RESULTS AND DISCUSSION)
MEASURING EFFECTS USING INCORRECT INTERCEPTS AS A DEPENDENT VARIABLE (SAS5-FI)

Source	Error	df (Source,Error)	MS (Effect)	MS (Error)	F-Stat	PR(f)	% Var
Disrupted Information Channel	Source x Subject	5,20	55.82	21.76	2.56	0.0599	4.30
Target	Source x Subject	7,28	42.26	15.70	2.69	0.0290	4.56
Subject	within cell	5,112	15.27	15.87	0.96	0.4450	1.18

* U.S. GOVERNMENT PRINTING OFFICE 1984 - 559-006/10223